Distributed Haptic Environments

1. Research Team

Project Leader: Prof. Gaurav S. Sukhatme, *Computer Science*

Other Faculty: Prof. Margaret McLaughlin, *Annenberg School for Communication*

Graduate Students: Wei (Rachel) Peng, Weirong (Wayne) Zhu,

2. Statement of Project Goals

In many applications of haptics it will be necessary for users to interact with each other as well as with other objects. We have developed architecture, for haptic collaboration among distributed users. Our focus is on collaboration over a non-dedicated channel (such as an Internet connection) where users experience stochastic, unbounded communication delays Adding haptics to multi-user environments creates additional demand for frequent position sampling for collision detection and fast update. It is also reasonable to assume that in multi-user environments, there may be a heterogeneous assortment of haptic devices (e.g. the PHANToM, the CyberGrasp, the iFeel mouse) with which users interact with the system. One of our primary concerns is thus to ensure proper registration of the disparate devices with the 3D environment and with each other.

3. Project Role in Support of IMSC Strategic Plan

A key component of the MIE is the existence of a virtual environment that is shared by multiple users at distinct locations. Several projects within IMSC address the multiple issues that need to be resolved to make the MIE a reality. This is one of these projects. Although we are currently focusing our attention on the collaboration of haptics devices, the architecture under development is designed to accommodate non-haptic components.

4. Discussion of Methodology Used

Our goal is to design an architecture that will support collaborative touch in virtual environments. We term such environments a ***virtual haptic world***. As shown in Figure 1, users may have different kinds of haptic devices, such as the PHANToM, CyberGrasp, or a FEELit mouse, or they can just be viewers. Some of the participants in the haptic world may only provide virtual objects as a service to the remaining users. This would be the role, e.g., of a museum's server.

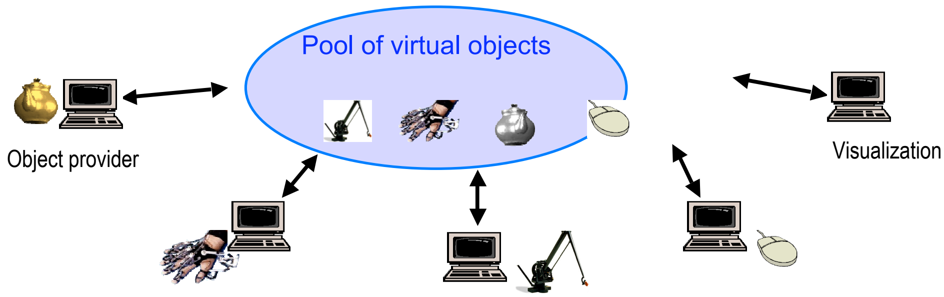

Figure 1**:** A virtual haptic world

From a computational perspective, a haptic world consists of a network of nodes. Each node corresponds to a computer whose operator is part of the shared virtual environment. The operator will typically interact with virtual objects through a haptic device but, conceivably, some users may interact with the haptic world using other modalities, e.g., by simple visualization. Some nodes may operate autonomously (i.e., without a human operator) and simply provide virtual objects for the haptic world.

Each node in the haptic world contributes to the shared environment with virtual objects. These can be static, e.g., a sculpture "bolted" to the ground, or dynamic, e.g., a teapot that can be virtually manipulated. We view the haptic devices that the human operators use to interact with the haptic world as dynamic objects. Each object in the haptic world is *owned* by one of the nodes, which is responsible for defining how its dynamic properties evolve. Typically, a node that is physically connected to a haptic device owns the object that represents the device.

Two databases are used to represent a haptic world. The *node database* contains information about the node network. It stores the logical identifiers and the IP addresses of all nodes, as well as the latency and available bandwidth between all nodes. The need for this information will become clear later. This database is dynamic because new nodes may join or leave the haptic world at run-time. The *object database* contains the information about all objects that are part of the haptic world. Each record in this database refers to a particular object and it contains the object identifier, the identifier of the node that owns it, its static properties (shape, size, color, etc.) and its dynamic properties (position, orientation, velocity, etc.).

The force control algorithms used for haptic rendering generally require high sampling rates (typically, on the order of 1KHz) and low latency (typically, on the order of a few milliseconds) [5]. This means that the databases need to be queried very frequently and with very low delay. Because of this it is necessary to distribute these databases by keeping local copies at each node. This allows for very fast access to the data about the objects that is needed for the force feedback loops, at the expense of the added complexity introduced by issues related to the consistency between the databases.

5. Short Description of Achievements in Previous Years

We have developed an architecture [10] for the real-time collection and simultaneous broadcast of haptic information to multiple haptic session participants, so that collaborative exploration of objects is possible, even when users are distributed across a network. The architecture relies on two distributed databases: the node and the object databases. These two databases are dynamic and need to be kept coherent among all nodes in the virtual haptic world. We have developed algorithms that keep these databases synchronized. These algorithms are independent of the actual haptic devices employed by each user [10]. The database synchronization mechanism was re-implemented as a collaboration library. This was done primarily to facilitate pilot studies where a user manipulating a PHANToM could touch a remote user wearing a CyberGrasp. To achieve the desired visual and haptic capabilities for the collaboration program, a model of a human hand was developed for the computer to which the PHANToM was connected. Each segment of the hand is a 3D model. Each component of the hand (the palm, the three segments of each finger, and the two segments of the thumb), were imported separately into the haptic environment. The components were arranged and aligned visually to produce the image of the hand.

5a. Detail of Accomplishments During the Past Year

During the past year, we continued to improve the haptic collaboration architecture, which includes three components: Graphic, Haptic, and Data synchronization. The graphics component is about how to show the virtual world on the computer screen, and we usually implement it by OpenGL. The haptic component is about how to let haptic devices produce real force feedback in the virtual world according to the physics of the real world. Each haptic device has its own device driver and software development kit. How to use heterogeneous haptic devices in the same virtual world is an open question. The data synchronization component is used to synchronize haptic data among different nodes over the network. This component was made into a software library. Because haptic data should be refreshed at almost 1kHZ to produce real force feed back, the data synchronization component is a basic building block on which the other two components in haptic collaboration are created. Over the past year, we have focused mainly on making the following modifications to the data communication component.

During our previous work, we used TCP package in data synchronization. But later, we found that the UDP package was more suitable for haptic data synchronization. TCP is a reliable protocol, and its packets are received in sending order. But for haptic data, minimizing network delay is more important than reliable data transmission. The UDP protocol can let the latest remote haptic data be sent to local graphic and haptic component as early as possible.

Remote nodes and objects can be added into or deleted from the local database automatically. When the data synchronization component receives a data package, including the dynamic properties of an object (e.g. position, velocity, etc.), if it found that the remote object and its node was not listed in the local database, it will add the node into the local database and send a message back to download the static properties of that remote object. Also if the data synchronization component has not received a data package from one node for a long time, the node and its object will be deleted from the local database.

A local group can be formed to reduce network traffic by the estimation of network delay. If network delay between two nodes is too long, it is useless to synchronize haptic data between them at a high rate, and also their network traffic will affect the data synchronization among other nodes. As a result, remote objects inside the local group will have less network delay and can respond to local haptic devices.

6. Other Relevant Work Being Conducted and How this Project is Different

There have only been a few studies of cooperation/collaboration between users of haptic devices. In a study by Basdogan, Ho and their colleagues [1,2], partners at remote locations were assigned three cooperative tasks requiring joint manipulation of 3D virtual objects, such as moving a ring back and forth along a wire while minimizing contact with the wire. Experiments were conducted with visual feedback only, and with both visual and haptic feedback. Both performance and feelings of togetherness were enhanced in the dual modality condition. Performance was best when visual feedback alone was followed by the addition of haptic feedback rather than vice versa. Durlach and Slater [3] note that factors that contribute to a sense of copresence include being able to observe the effect on the environment of actions by one's interlocutors, and being able to work collaboratively with copresent others to alter the environment. Point of view (egocentric vs. exocentric) with respect to avatars may also influence the sense of copresence. Touching, even virtual touching, is believed to contribute to the sense of copresence because of its associations with closeness and intimacy. Our work differs from related work at MIT, Uppsala, U. of Tokyo in that it is grounded in a distributed architecture for real-time collection and simultaneous broadcast of haptic information to multiple haptic session participants. Further, it permits participation by users with disparate haptic devices (PHANToM (6DOF, 3DOF), CyberGrasp, iFeel, CyberGlove). Our work also allows for users to touch each other as well as objects in the environment. And finally, our design maintains stability by addressing issue of latency; interaction between two hosts is decided dynamically based on the measured network latency between them.

7. Plan for the Next Year

Currently, we are adding prediction and interpolation into the haptic collaboration to reduce network traffic and the impact of network delay. The same prediction and interpolation method will be applied to both sides of synchronization. For example, if the position of an object should be synchronized in the local group, the object owner will first predict the position based on the historical data. The object owner will not send out data until the difference between the predicted position and real position is out of an acceptable range, because the receiver will be assumed to use the same prediction method to interpolate the position of this remote object at the same time. However, if both sides make wrong predictions due to different historical data or because of not considering the network delay, incorrect prediction and interpolation can make haptic collaboration even worse. To prevent this from happening, we plan to make experiments to find a suitable prediction method.

8. Expected Milestones and Deliverables

- Development of the basic haptic collaboration architecture to share a virtual environment between PHANToMs and CyberGrasps.
- 3D visualization of haptic environments using the immersadesk

- Integration of the haptics with other modalities, such as, simulated contact sounds (3D), voice.
- Integration of haptic collaboration with other IMSC projects (e.g., the Haptics Museum and BioSIGHT).

9. Member Company Benefits

N/A

10. References

[1] C. Basdogan, C. Ho, M. Slater, and M. A. Srinivasan, "The Role of Haptic Communication in Shared Virtual Environments," PHANToM Users Group, 1998 (http://www.sensable.com/community/PUG98/19_basdogan.pdf).

[2] C. Ho , C. Basdogan, M. Slater, N. Durlach, M. A. Srinivasan , "An Experiment on the Influence of Haptic Communication on the Sense of Being Together," 1998 (http://www.cs.ucl.ac.uk/staff/m.slater/BTWorkshop/touchexp.html).

[3] N. Durlach and M. Slater, "Presence in Shared Virtual Environments and Virtual Togetherness," 1998 (http://www.cs.ucl.ac.uk/staff/m.slater/BTWorkshop/durlach.html).

[4] Buttolo, P., J. Hewitt, R. Oboe, and B. Hannaford, "Force Feedback in Virtual and Shared Environments," 1997 (http://brl.ee.washington.edu/BRL/publications/Rep100.ps).

[5] Wilson, J. P, Kline-Schoder, R. J., Kenton, M. A., and Hogan, N, "Algorithms for Network-Based Force Feedback," in Salisbury, J. K. and Srinivasan, M. A. (Eds), Proc. PHANTOM Users Group Workshop, MIT 1999.

[6] McLaughlin, M. L., Sukhatme, G., Hespanha, J., Shahabi, C., Ortega, A., & Medioni, G "The Haptic Museum," Proc. EVA 2000, Conference on Electronic Imaging and the Visual Arts, 2000.

[7] McLaughlin, M. L., G. Sukhatme, J. Hespanha, C. Shahabi, and A. Ortega, "Touch in Immersive Environments," Proc. EVA 2000 Conference on Electronic Imaging and the Visual Arts, Edinburgh, Scotland, 2000.

[8] McLaughlin, M. L., Hespanha, J., & Sukhatme, G. (Eds.). Touch in Virtual Environments: Haptics and the Design of Interactive Systems. IMSC Press Multimedia Series. Prentice-Hall, 2002.

[9] McLaughlin, M. L., Hespanha, J. and Sukhatme, G. Introduction to haptics. In McLaughlin, M. L., Hespanha, J., & Sukhatme, G. (Eds.). Touch in Virtual Environments: Haptics and the Design of Interactive Systems. Prentice-Hall, 2002.

[10] Hespanha, J., McLaughlin, M., and Sukhatme, G. Haptic collaboration over the Internet. In McLaughlin, M. L., Hespanha, J., & Sukhatme, G. (Eds.). Touch in Virtual Environments: Haptics and the Design of Interactive Systems. Prentice-Hall, 2002.